



“Lepton flavour universality test at NA62 (CERN)”

Madison 09/05/2011

Domenico Di Filippo

Università degli studi di Napoli “Federico II”

And INFN Napoli

On behalf of the *NA62 collaboration*:

Bern ITP, Birmingham, CERN, Dubna, Ferrara, Fairfax, Florence, Frascati,
IHEP, INR, Louvain, Mainz, Merced, Naples, Perugia, Pisa, Rome I,
Rome II, San Luis Potosi, SLAC, Sofia, Triumf, Turin

Ke2: R_K and LFV

- The hadronic uncertainties cancel in the ratio $K_{e2}/K_{\mu 2}$ (**no f_K**)
- For this reason the SM prediction is very accurate $dR_K/R_K \sim 0.04\%$

$$R_K^{SM} = \frac{\Gamma(K \rightarrow e \bar{v}_e)}{\Gamma(K \rightarrow \mu \bar{v}_\mu)} = \frac{m_e^2}{m_\mu^2} \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2} \right)^2 (1 + \delta R_{QED}) =$$

$$= (2.477 \pm 0.001) \cdot 10^{-5}$$

[V.Cirigliano, I.Rosell JHEP 0710:005(2007)]

[Masiero at all PRL 99 (2007) 231801]

- The only difference between electron and muon channel is due to the **V-A coupling**
- A small correction has to be included due to the IB part of the radiative decay

R_K Beyond Standard Model

In **MSSM** and large $\tan\beta$ scenario, a charged Higgs mediate a **SUSY LFV contribution** to the branching ratio with emission of ν_τ .

$$R_K^{LFV} = 2 \frac{\Gamma_{SM}(K \rightarrow e\nu_e) + \boxed{\Gamma_{LFV}(K \rightarrow e\nu_\tau)}}{\Gamma_{SM}(K \rightarrow \mu\nu_\mu)} = \\ = R_K^{SM} \left[1 + \left(\frac{m_K}{m_H} \right)^4 \left(\frac{m_\tau}{m_e} \right)^4 |\Delta_{13}|^2 \tan^6 \beta \right]$$

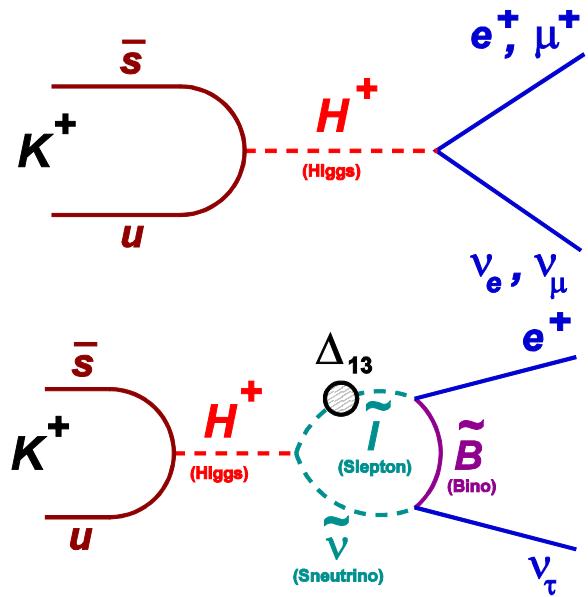
A.Masiero, P.Paradisi, R.Petronzio,

PRD74 (2006) 011701 and JHEP 0811(2008) 042

Sizeable **effects** are predicted for reasonable SUSY parameters.:

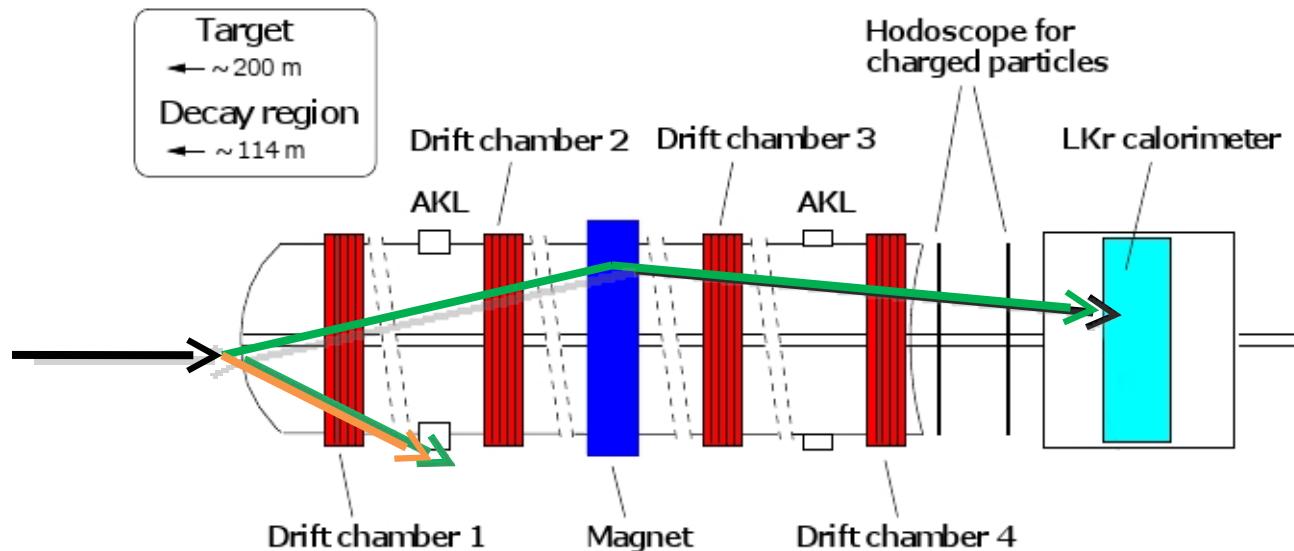
$$\Delta_{13} = 5 \cdot 10^{-4}, \tan\beta = 40, m_H = 500 \text{ GeV} \Rightarrow R_K^{LFV} \sim R_K^{SM} (1 + 0.013)$$

Analogous effects in Pion decays are suppressed by a factor $(m_p/m_K)^4 \sim 6 \cdot 10^{-3}$



K_{e2} @ NA62-I (2007-2008)

[Phys. Lett. B698 (2011) 105]



- Goal: collect ~ 150000 signal events, better than 0.5% precision on R_K
- Simultaneous K_{e2} and $K_{\mu 2}$ collection (both for K^+ and K^-)
- about 80% K^+ (used for the analysis) due to the fact that K^- are affected by a larger halo background

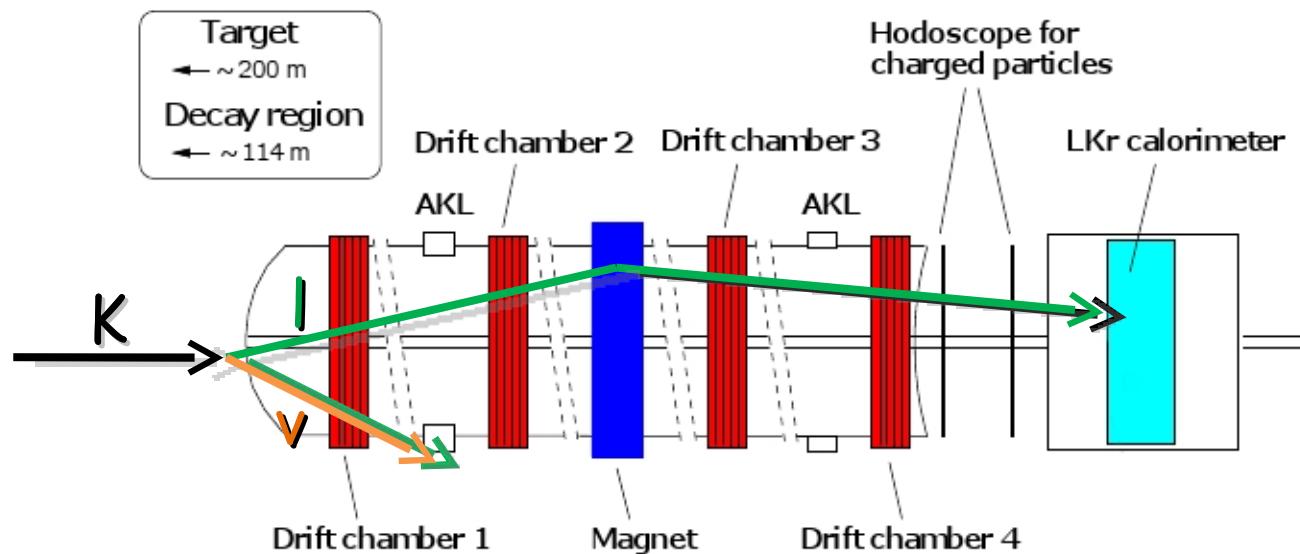
NA62-I apparatus

Magnetic spectrometer

- > 4 view / DCH -> high efficiency
- > $\sigma_p/p = 0.48\% + 0.009\% \cdot p$ [GeV/c]

Hodoscope

- > Fast trigger
- > $\sigma_t = 150\text{ps}$



Electromagnetic calorimeter

- > $\sim 7\text{ m}^3$ liquid krypton ($\sim 27 X_0$)
- > High granularity, quasi-homogeneous
- > $\sigma_E/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\%$ [GeV]
- > $\sigma_{x,y} \sim 1\text{ mm}$ (@ 20 GeV)

Measurement strategy

K_{e2} and $K_{\mu 2}$ candidates collected simultaneously:

- > Many systematic effects reduced,
- > Measurement independent of the Kaon flux.

Particle identification with E/p (LKr and spectrometer)

MC simulations used to limited extent:

- > Acceptance correction (only for geometry),
- > Simulation of “catastrophic” bremsstrahlung by muons.

Analysis in 10 track momentum bins.

$$R_K = \frac{1}{D} \frac{\frac{N(K_{e2}) - N_B(K_{e2})}{N(K_{\mu 2}) - N_B(K_{\mu 2})}}{\frac{f_m \cdot A(K_{\mu 2}) \cdot \epsilon(K_{\mu 2})}{f_e \cdot A(K_{e2}) \cdot \epsilon(K_{e2})}} \frac{1}{f_{LKR}}$$

Signal events *Particle ID efficiency* *Trigger Efficiency (>99.9%)*

$K_{\mu 2}$ downscaling *Background Events (Main source of systematic errors)* *Geometrical acceptance* *Global LKr readout eff (0.998)*

Signal selection

Common reconstruction:

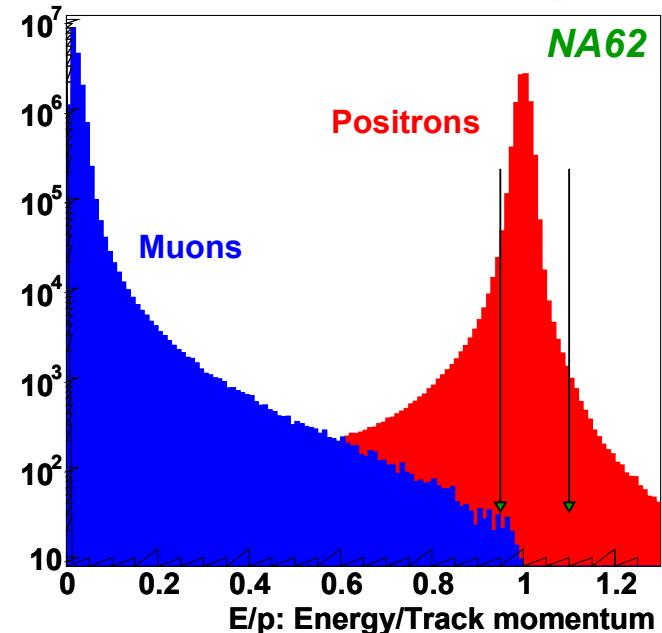
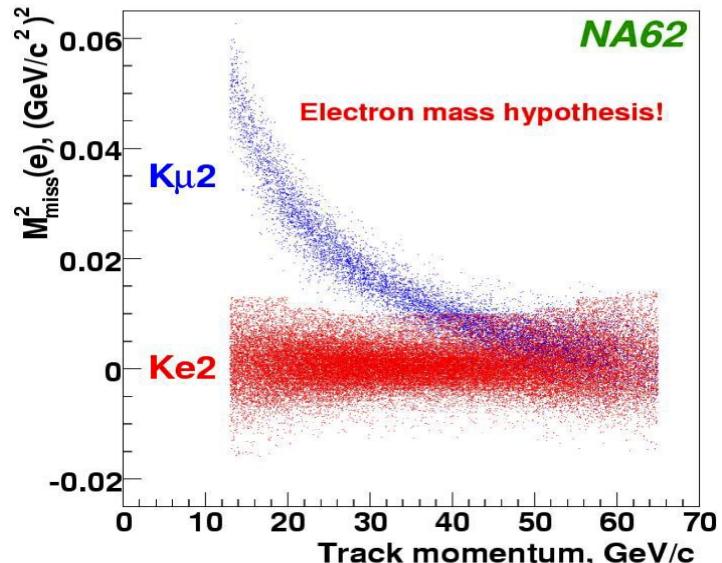
- > 1 Reconstructed Track,
- > Geometrical acceptance cuts,
- > Limit on LKr extra energy deposition,
- > Track momentum $13 \text{ GeV}/c < p < 65 \text{ GeV}/c$
- > Decay vertex defined as closest approach of track & nominal Kaon axis.

Kinematical separation => Excellent $K_{e2}/K_{\mu 2}$ separation at $p < 25 \text{ GeV}/c$:

- > Missing mass $M^2 = (p_K - p_l)^2$
- > P_K : Average measured with $K_{3\pi}$ decays

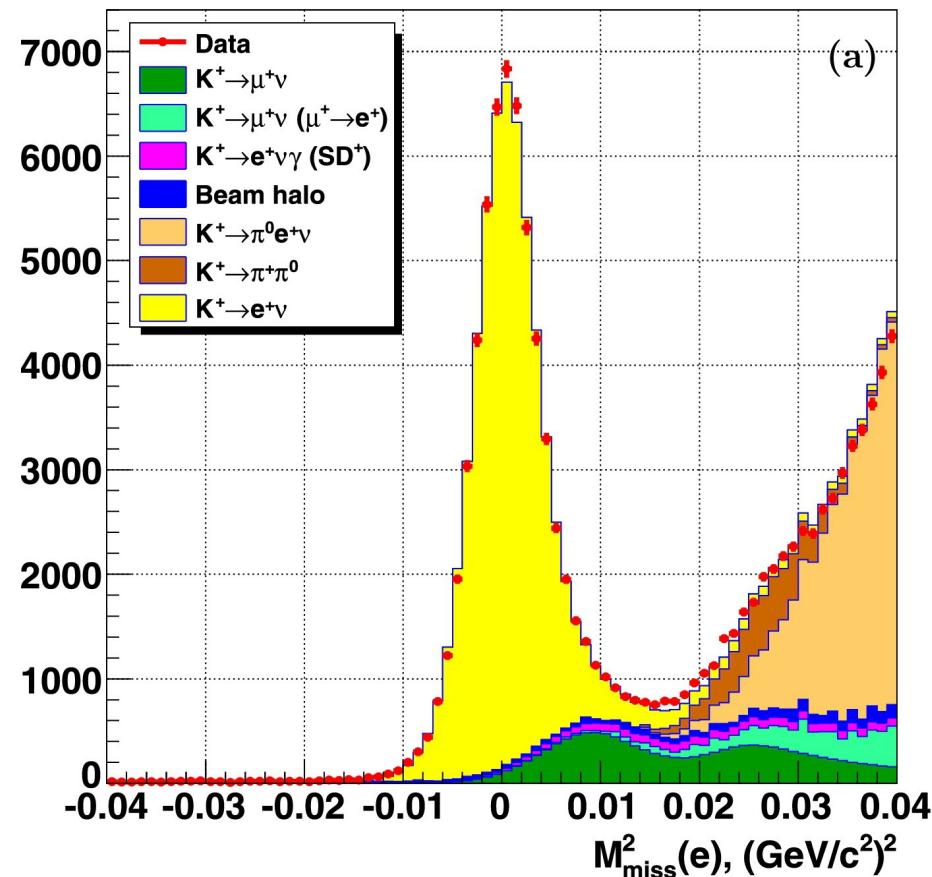
Particle Identification => Muon suppression $\sim 10^{-6}$

- > $E/p = (\text{LKr energy deposit}/\text{track momentum})$
- $0.90 < E/p < 1.10$ for electrons with $P \leq 25 \text{ GeV}$,
- $0.95 < E/p < 1.10$ for electrons with $P > 25 \text{ GeV}$,
- $E/p < 0.85$ for muons.



K_{e2} Backgrounds

- Muon $B/S = (6.11 \pm 0.22)\%$
Measured with special runs with lead wall
- Beam Halo $B/S = (1.16 \pm 0.06)\%$
Directly measured on the data with special runs
- Muon decay $B/S = (0.27 \pm 0.04)\%$
Measured with MC including also the contribution of m decay in spectrometer
- $Ke2\gamma$ $B/S = (1.07 \pm 0.05)\%$
Limited by the error on the measured BR (20%). Strong improvement expected by our new measurement in this channel
- $Ke3$ $B/S = (0.05 \pm 0.03)\%$
- $K2\pi$ $B/S = (0.05 \pm 0.03)\%$
- f_e uncertainty $<0.1\%$
Very high ID efficiency $f_e = (99.3 \pm 0.05)\%$ measured with charged $Ke3$ from nominal data taking and $KLe3$ from KL special runs



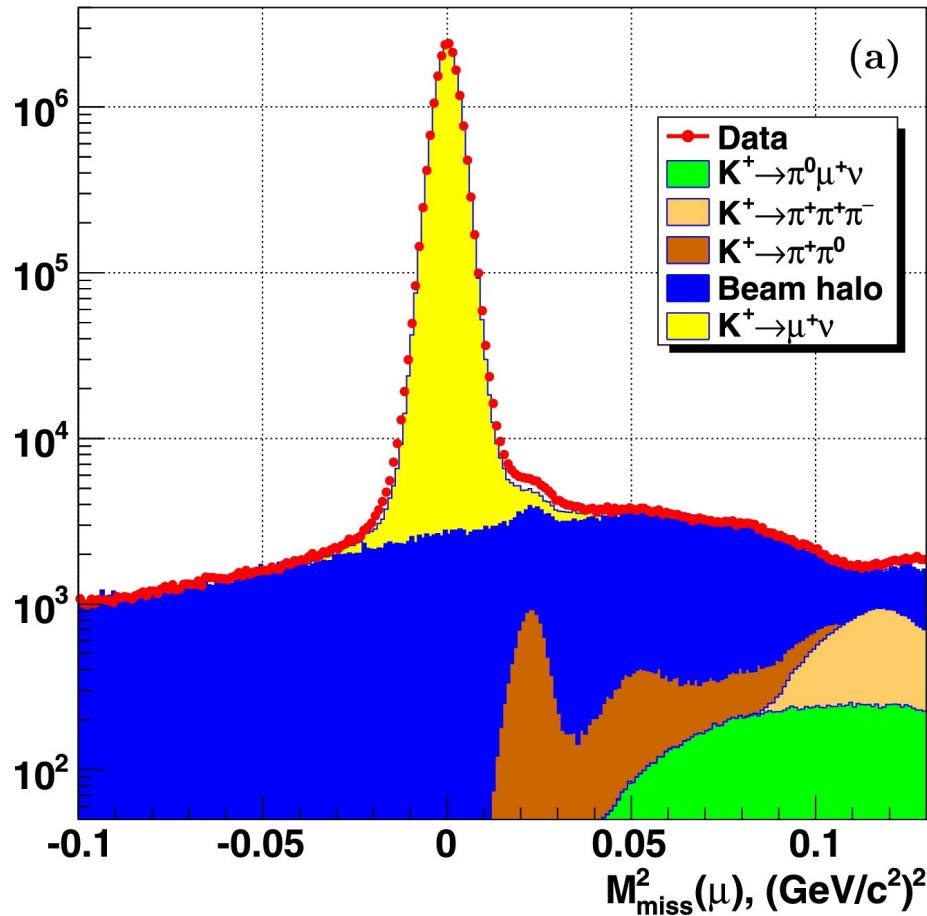
Analysis on 40% dataset,
 $59813 K_{e2}$ events, $B/(S+B) = (8.71 \pm 0.24)\%$
NA62 proposal the goal was $\sim 150k$ (CERN-SPSC-2006-033)..

$K_{\mu 2}$ backgrounds

The $K_{\mu 2}$ is downscaled by a factor of 150

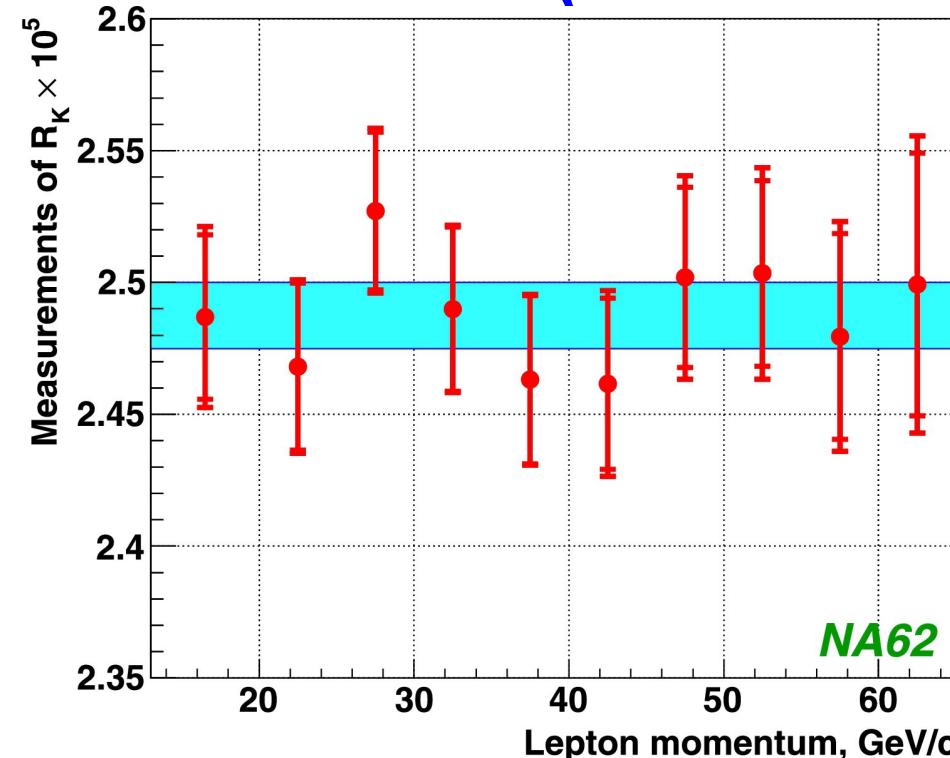
The $K_{\mu 2}$ main background is the Beam Halo.

18.03M $K_{\mu 2}$ candidates with low background $B/(S+B) = (0.38 \pm 0.01)\%$



R_K results (40% data set)

$$R_K = (2.487 \pm 0.011_{\text{stat}} \pm 0.008_{\text{syst}}) \times 10^{-5}$$
$$= (2.487 \pm 0.013) \times 10^{-5} \text{ (arXiv:1101.4805)}$$

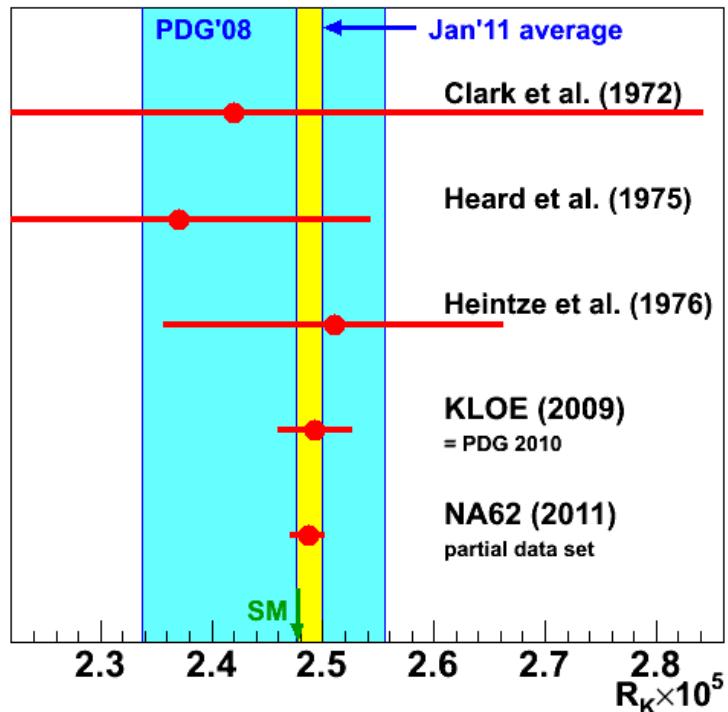


Source	$\delta R_K \times 10^5$
Statistical	0.011
$K_{\mu 2}$ background	0.005
$K^+ \rightarrow e^+ \nu \gamma$ (SD ⁺) background	0.001
$K^+ \rightarrow \pi^0 e^+ \nu, K^+ \rightarrow \pi^+ \pi^0$ backgrounds	0.001
Beam halo background	0.001
Helium purity	0.003
Acceptance correction	0.002
Spectrometer alignment	0.001
Positron identification efficiency	0.001
1-track trigger efficiency	0.002
LKr readout inefficiency	0.001
Total systematic	0.007
Total	0.013

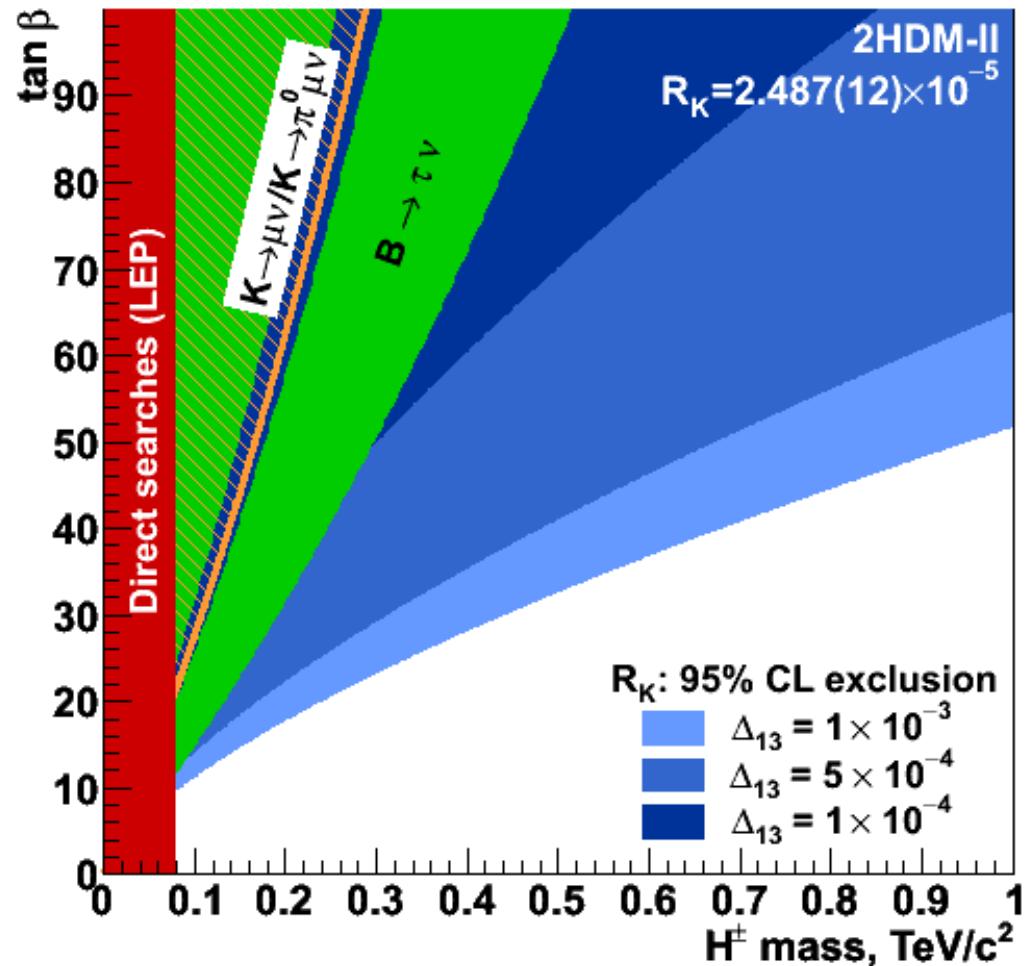
Precision 0.52%

The whole sample will decrease the statistical uncertainty down to ~0.3% and a total uncertainty of 0.4%

World comparison

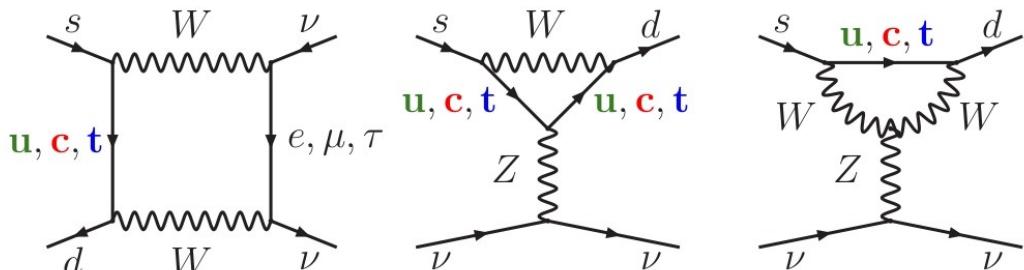


$$R_K \sim (2.487 \pm 0.012) \times 10^{-5} \quad (\text{precision } 0.48\%)$$



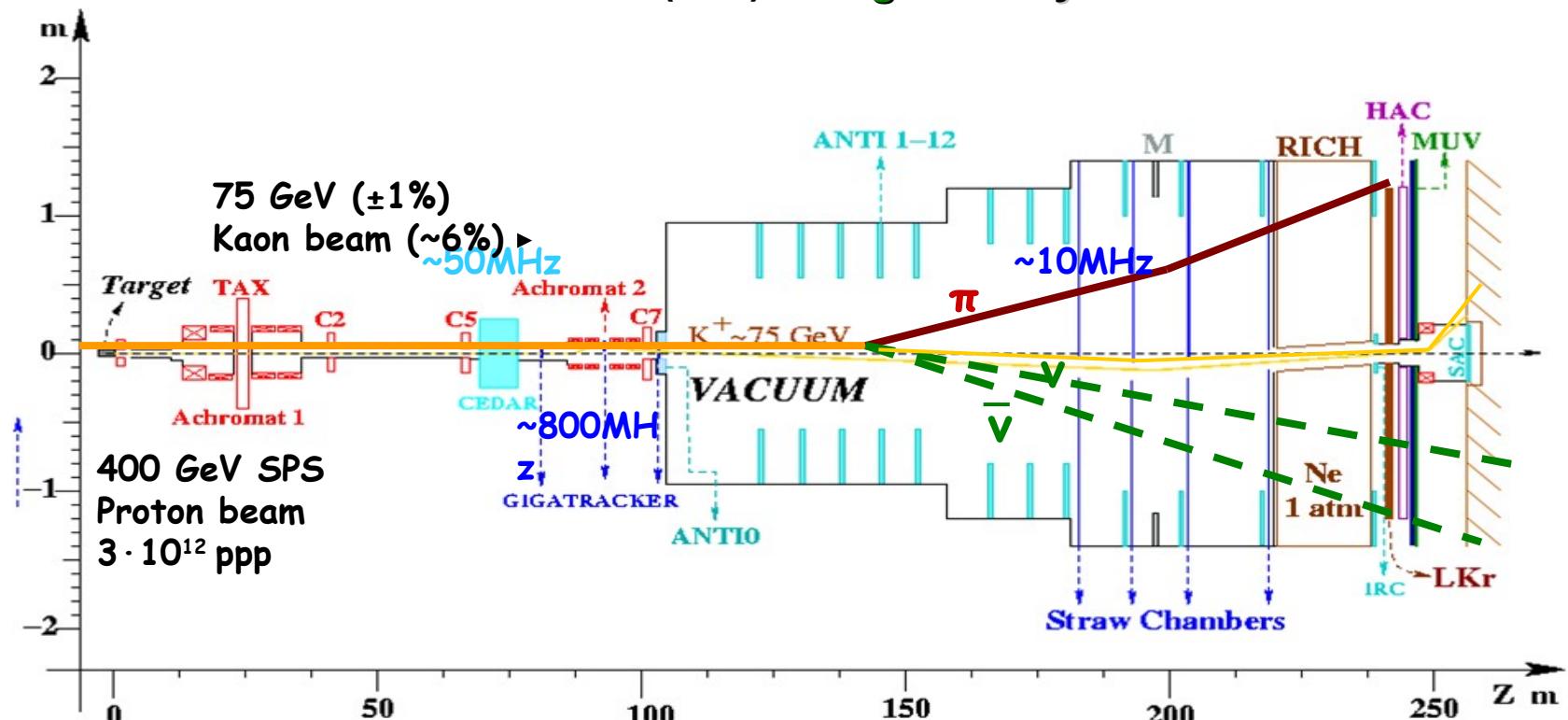
NA62 phase II: $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

Only one loop contributions:
Boxes and Penguins



Theoretical prediction (8%):
 $\text{BR}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (8.5 \pm 0.7) \times 10^{-11}$

- NA62-II Goal: Collect O(100) **in flight** decay with S/B ~10

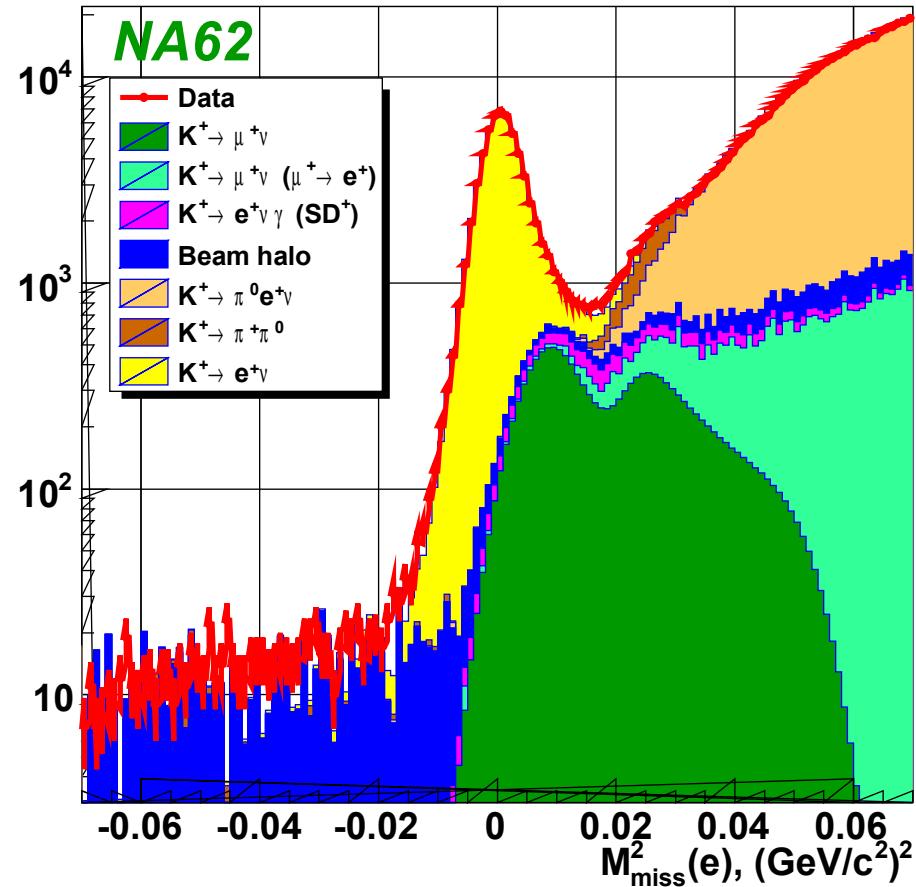
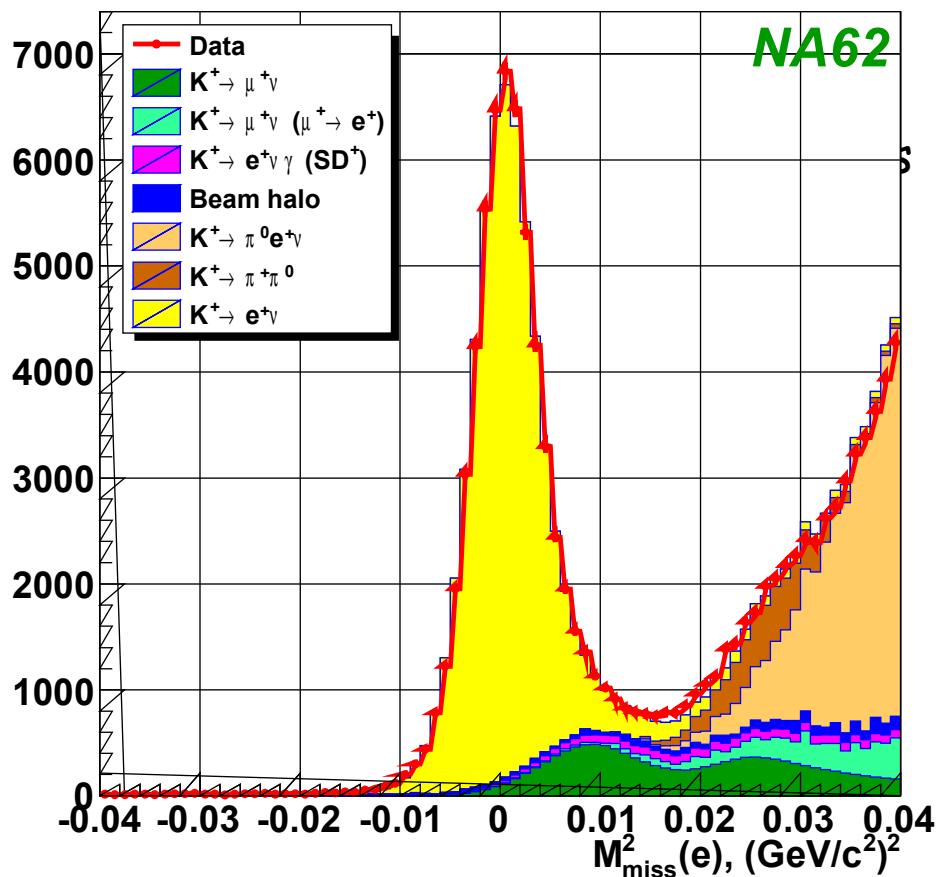


Conclusion

- In the flavour sector, new physics could appear both in **MFV** and in **NON-MFV** processes
- A precise R_K measurement in the **Ke2 decay** is a very powerful tool to constrain new physics parameters in case of presence of **LFV mediators**
- **NA62-I** reached a sensitivity of **0.5%**
- The measurement of the **$K^+ \rightarrow \pi^+ vv$** decay could be a good opportunity to find NP and to distinguish among NP models
- **NA62-II** is a challenging experiments aiming at $O(100)$ events with $S/B=10$
- Detectors R&D will be completed until 2012. The data taking should start in the 2013-14.

Spares

K_{e2} : 40% of data set



The present statistics gives $59813 K_{e2}$ candidates events and $B/(S+B)=(8.71\pm 0.24)\%$.

In NA62 proposal the goal was $\sim 150k$ (CERN-SPSC-2006-033).

Outline

- **NA62-I: R_K with $K/2$ decays**

- principle of the measurement
- analysis review

- **NA62-II: $K^+ \rightarrow p^+ \bar{n}n^-$ experiment**

..at the heart of LHC

NA48 \rightarrow NA62

- experimental methodology
- main detectors description
- Conclusions

R_K Experimental Status

-> The **PDG08** value is based on 3 measurements in 70s

$$R_K = (2.45 \pm 0.11) \cdot 10^{-5} \text{ (4.5% error)}$$

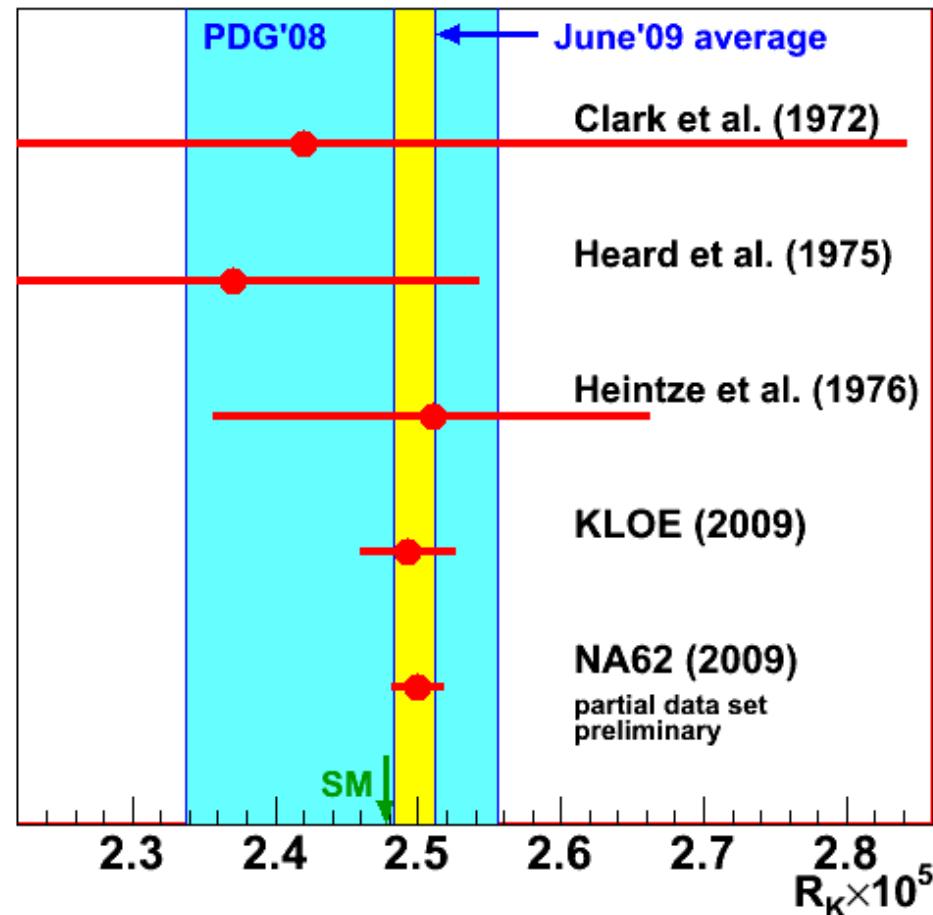
-> Final result by **KLOE** (LaThuile09)

$$R_K = (2.493 \pm 0.025 \pm 0.019) \cdot 10^{-5}$$

(1.3% err with $\sim 13.8k$ K_{e2} candidates, 16% background)

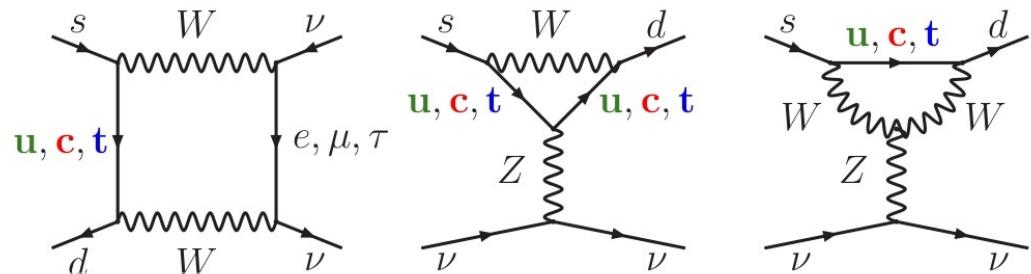
PDG 2010 World average

$$R_K = (2.498 \pm 0.014) \cdot 10^{-5} \text{ (0.56% error)}$$



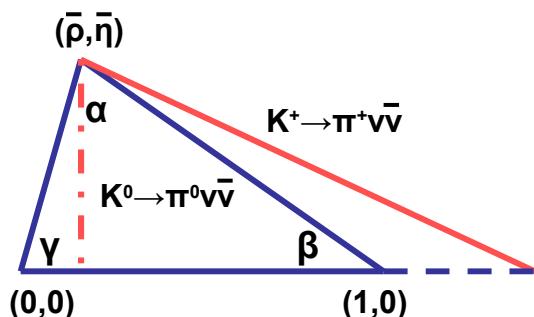
$K^+ \rightarrow p^+ \bar{n}n$: motivation

- **FCNC** process forbidden at tree level
- Only one loop contributions: **Boxes** and **Penguins**



Theoretical prediction:

$$BR(K^+ \rightarrow p^+ \bar{n}n) = (8.5 \pm 0.7) \times 10^{-11} \quad \text{8% error}$$

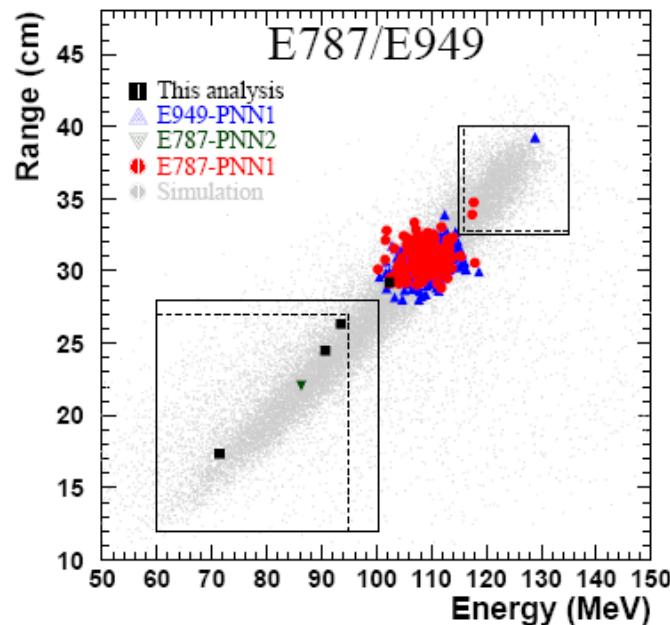
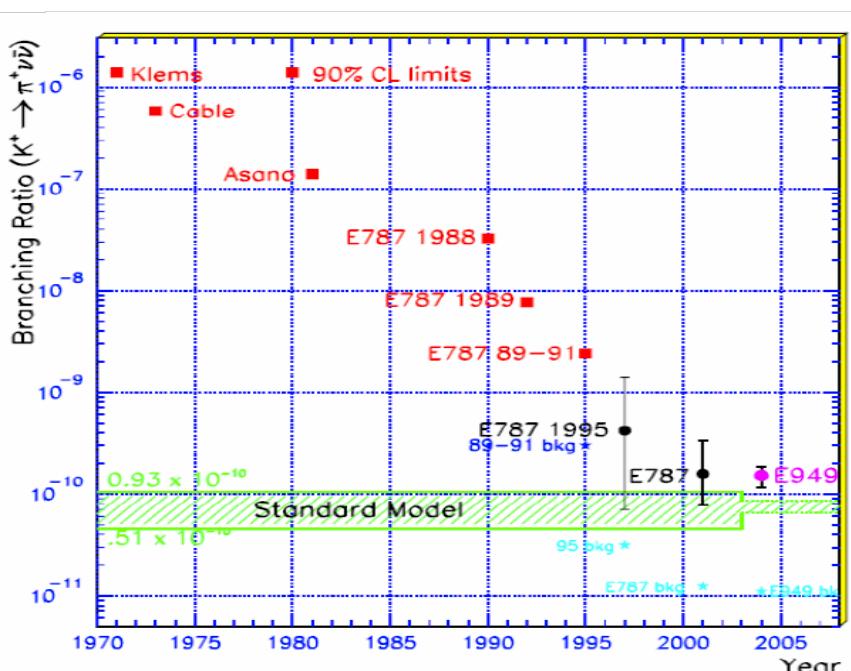


- Cleanest way to extract V_{td} and to give independent determination of the **unitarity triangle**
- Complementarity with B physics
- Very sensitive to New Physics

Experimental status

$$BR(K^+ \rightarrow p^+ nn)_{\text{exp}} = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$$

based on 7 candidates at BNL E787+E949

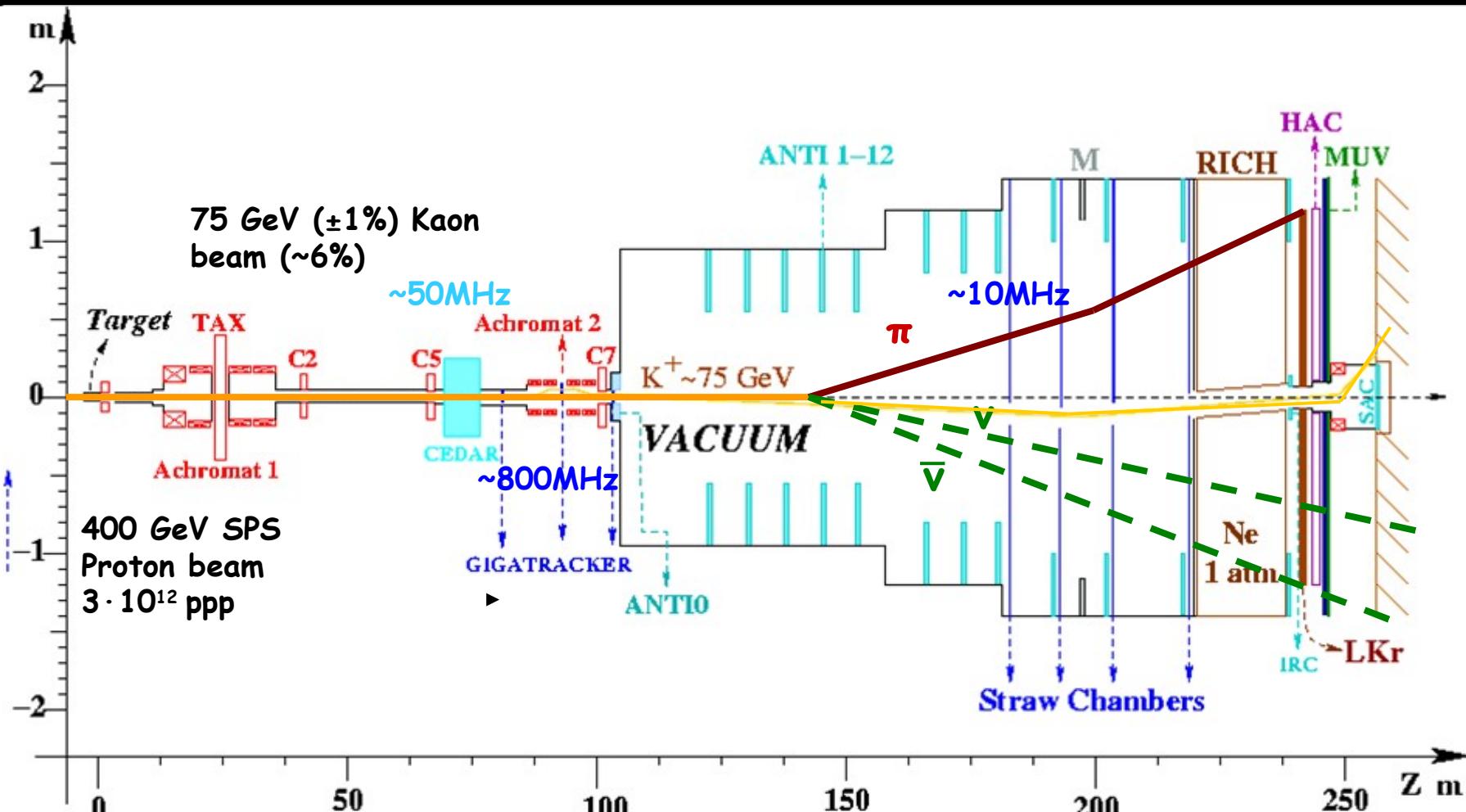


Probability that all 7 events are due to background: 10^{-3}

first experimental observation of $K^+ \rightarrow p^+ nn$

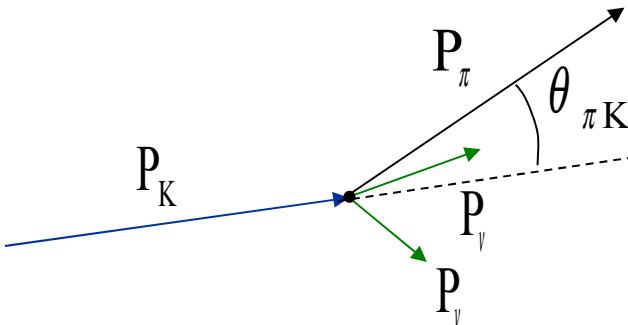
they have shown that all physics background can be under control at 10^{-11} level !

$K^+ \rightarrow p^+ \bar{n}n$ @ NA62-II



- High energy **unseparated** kaon beam
- Decay **in flight** technique
- **Goal:** $O(100)$ events with $S/B \sim 10$

Kinematic reconstruction



$$m_{miss}^2 \equiv m_K^2 \left(1 - \frac{|P_\pi|}{|P_K|} \right) + m_\pi^2 \left(1 - \frac{|P_K|}{|P_\pi|} \right) - |P_K||P_\pi| \theta_{\pi K}^2$$

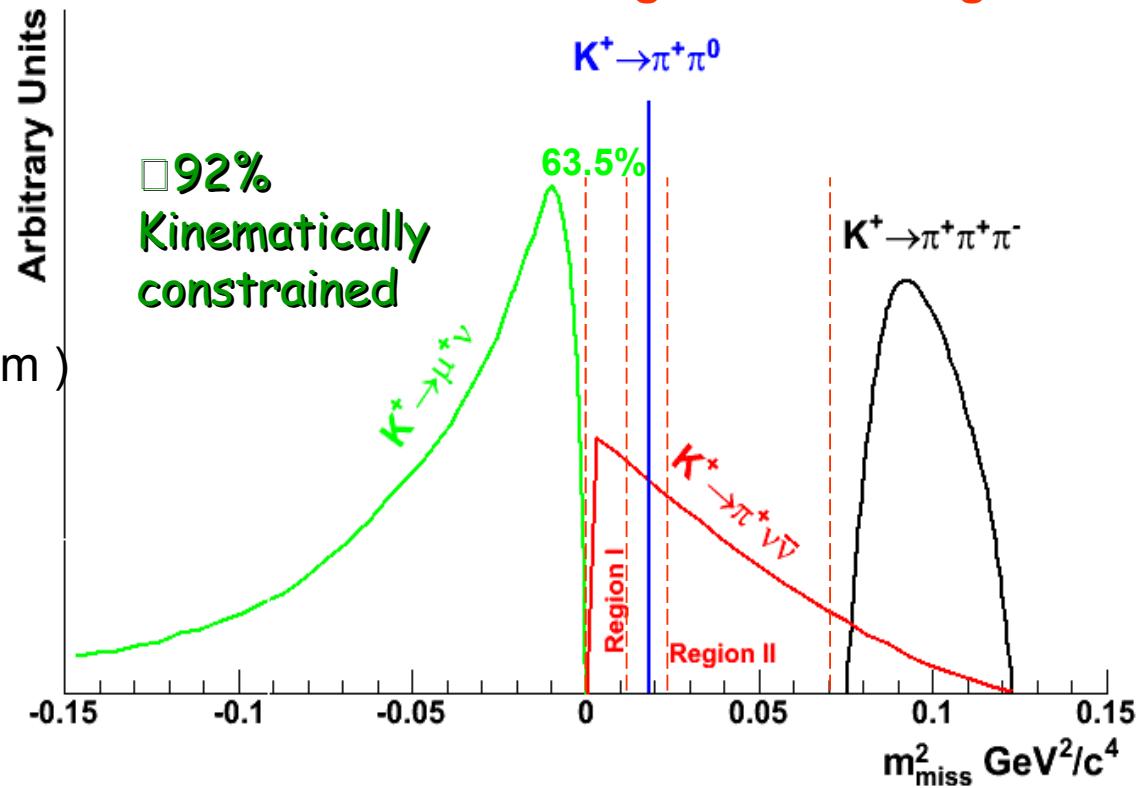
two background free regions

Requirements:

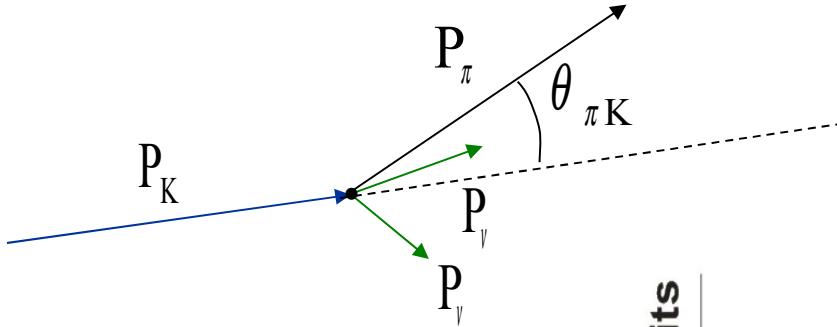
- low mult. scattering
→ low mass tracker operating in vacuum
- good space resolution ($\square 100$ mm)

Detectors:

- GigaTracker
- Straw Chamber Spectrometer



PID and Veto

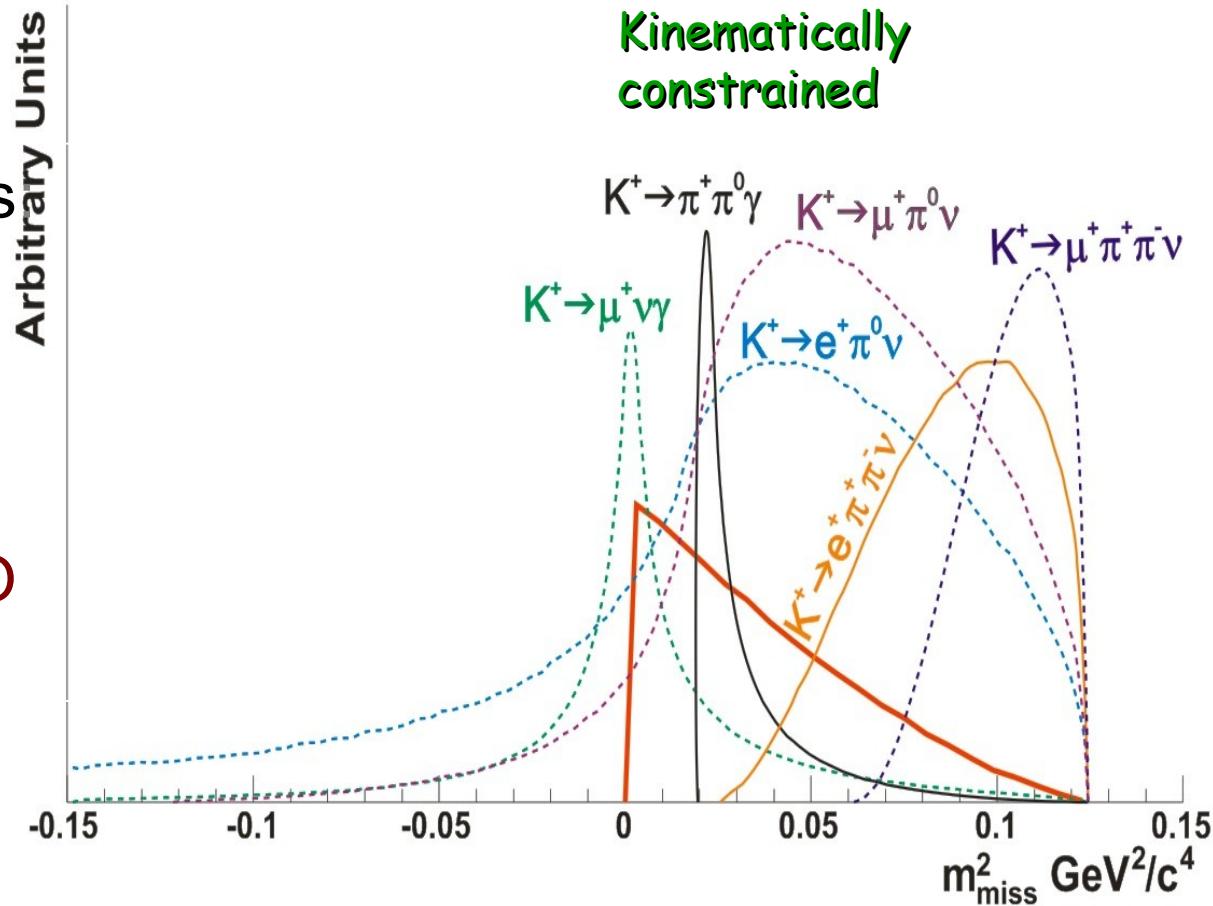


□ 8% not
Kinematically
constrained

high efficiency detectors

Photon veto:
 $K^+ \rightarrow p^+ p^0$ supp.

RICH and MUON VETO
for muon suppression



Kaon and Physics beyond the SM

New physics effects in Flavour Physics

[G.Isidori Capri, Flavianet 2008]

MFV: helicity suppressed observables are sensible to SUSY with large $\tan\beta$:
 $B \rightarrow ll$, $B \rightarrow ln$, $K \rightarrow ln$

The B decays are suppressed ($V_{ub} \ll V_{us}$) while the $K \rightarrow en$ is $1.5 \cdot 10^{-5}$

Non-MFV: FCNC decays with high suppression in the standard model and clean theoretical prediction

The $K \rightarrow pnn$ has a very clean SM prediction and has a I^5 suppression

It's time for a precision measurement in K_{e2} and $K \rightarrow pnn$!!!

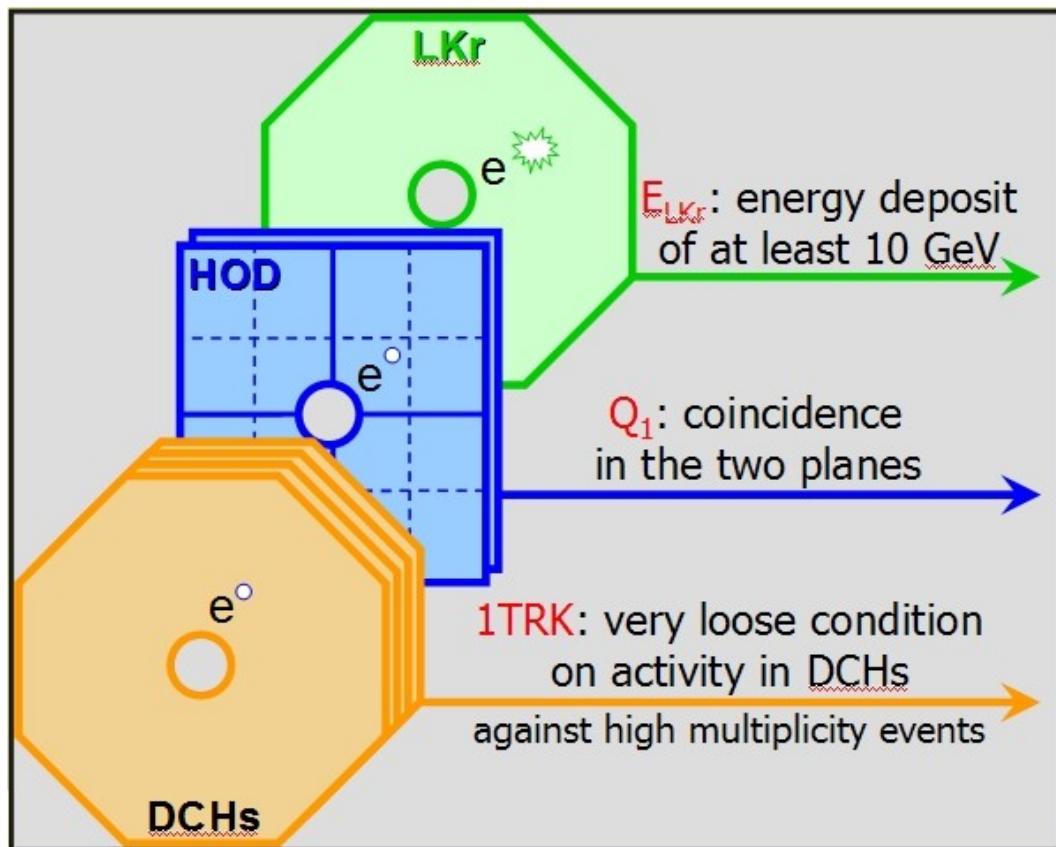
NA62-I
(2007/08)

Lepton universality in Kaon decays

NA62-II
(2013-14)

O(100) events measurement of $BR(K \rightarrow pnn)$

NA62-I: Triggers



Minimum Bias Hardware Trigger:

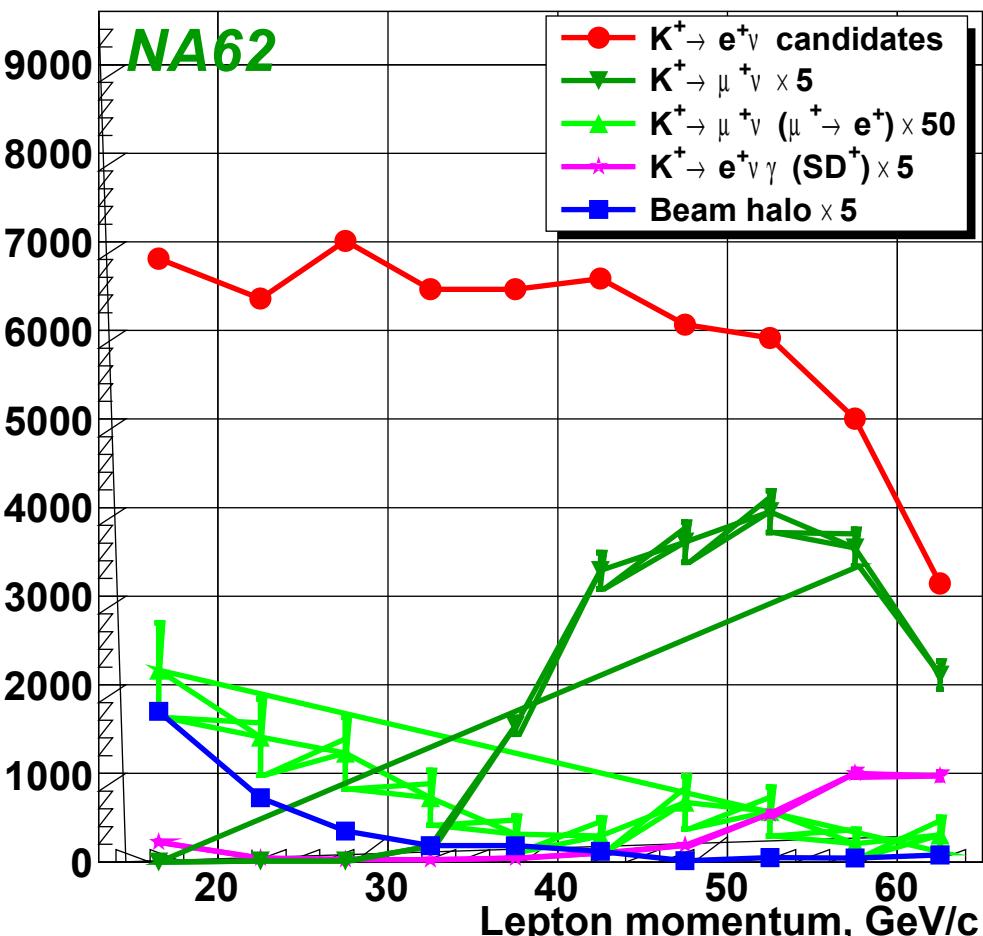
- > $K_{\mu 2}$ condition: 1TRK Q1
- > K_{e2} condition: 1TRK Q1 ELKr



Software Trigger:

- > $P_{DCH} < 90 \text{ GeV}/c$
- > $E_{LKr}/P_{DCH} > 0.6$ (K_{e2} only)

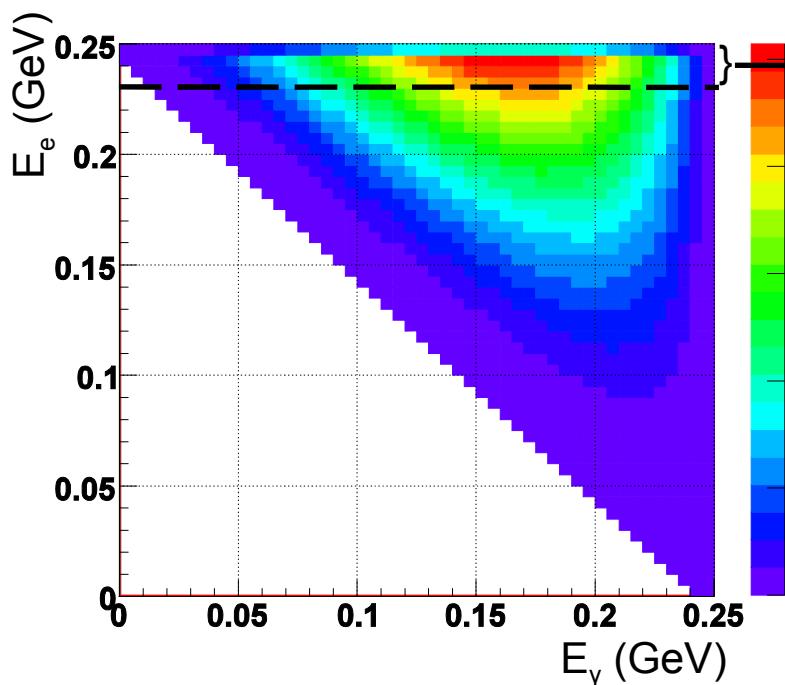
Backgrounds Summary



Source	$N_B/N(K_{e2})$
$K_{\mu 2}$	$(6.11 \pm 0.22)\%$
$K_{\mu 2}(\mu \rightarrow e)$	$(0.27 \pm 0.04)\%$
$K^+ \rightarrow e^+\nu\gamma (SD^+)$	$(1.07 \pm 0.05)\%$
$K^+ \rightarrow \pi^0 e^+\nu$	$(0.05 \pm 0.03)\%$
$K^+ \rightarrow \pi^+ \pi^0$	$(0.05 \pm 0.03)\%$
Beam halo	$(1.16 \pm 0.06)\%$
Total	$(8.71 \pm 0.24)\%$

Selection criteria has been **optimized individually** in each track momentum bin. (e.g. Z_{vertex} and $M_{\text{mis}}{}^2$)

Backgrounds



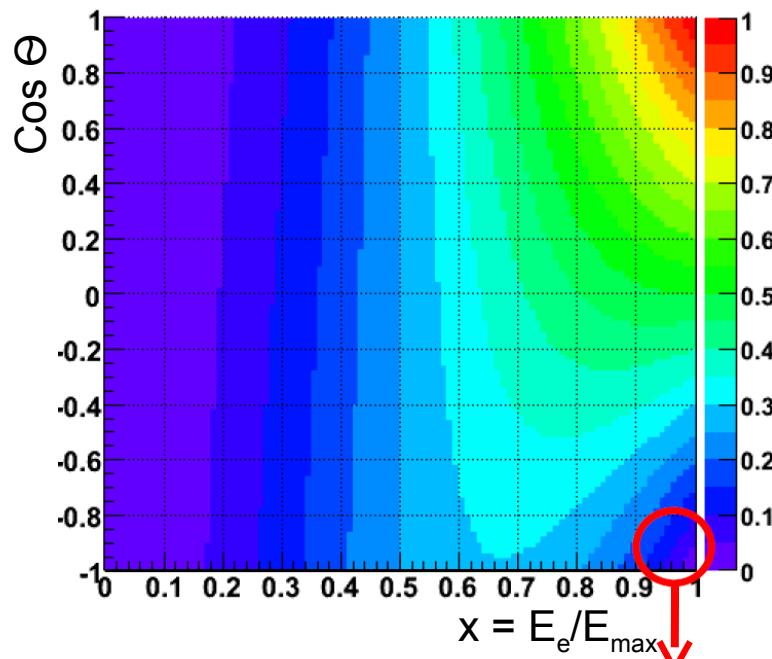
$K_{e2\gamma}$ experimental knowledge is in 70s:

$$\text{BR} = (1.52 \pm 0.23) \times 10^{-5}$$

$$B/(S+B) = (1.02 \pm 0.15)\%$$

Uncertainty to be improved by KLOE and NA62

Only energetic ($E > 230\text{MeV}$) electrons are compatible to K_{e2} kinematic ID

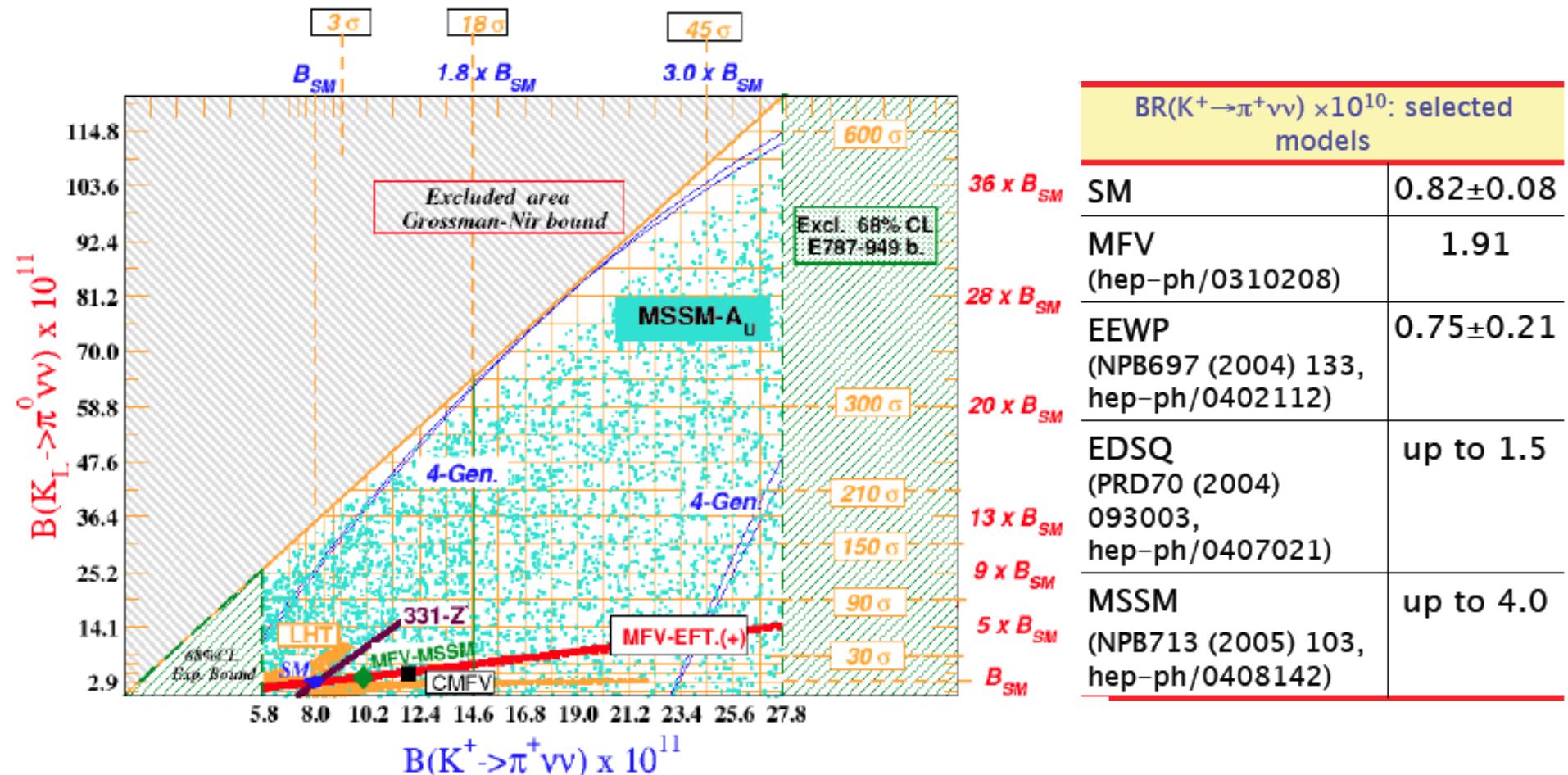


For BG due to in flight muons decays, according to Michel distribution in NA62 only energetic forward electrons are selected as K_{e2} candidate => Highly suppressed

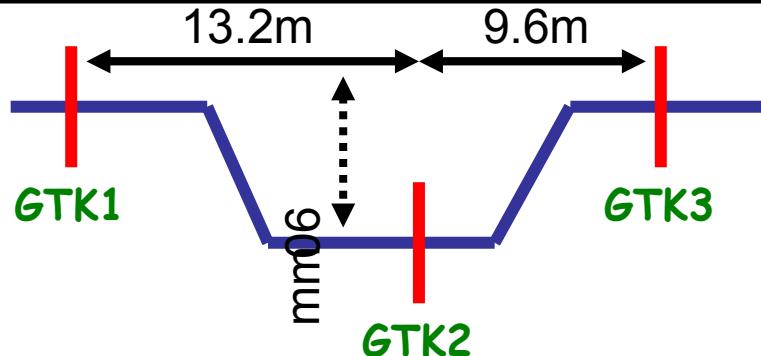
$$B/(S+B) = (0.23 \pm 0.01)\%$$

$K^+ \rightarrow p^+ \bar{n}n$: motivation (II)

Several NP models and possibility to distinguish among different models



NA62-II: Gigatracker

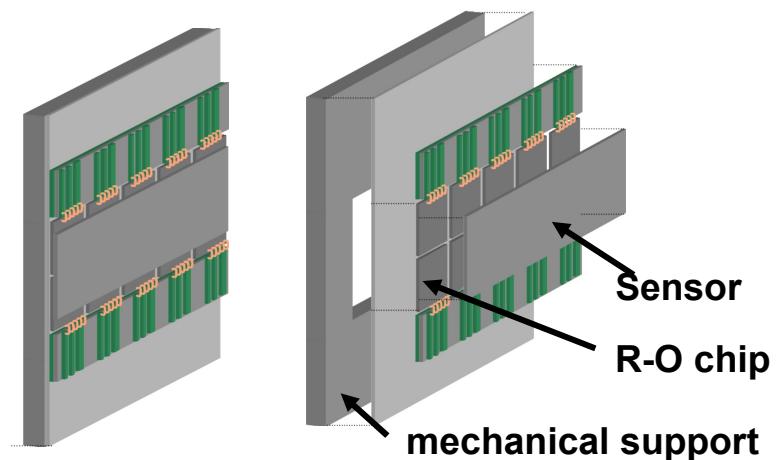


- Very **thin silicon sensor** and readout chip ($200+100\text{ mm} \sim 0.5X_0$)
- On site bump bonded readout chip
0.13 mm CMOS tech
- $60 \times 27\text{ mm}^2$ per station
- 300mmx300mm pixels

• Readout chip and sensor
Prototypes under construction
• Test beam in 2009

Requests:

- Beam spectrometer: 3 stations
- Good space resolution
- Low material budget
- Very high intensity hadron beam: **800MHz**
- Excellent time resolution: **200 ps**



Gigatracker

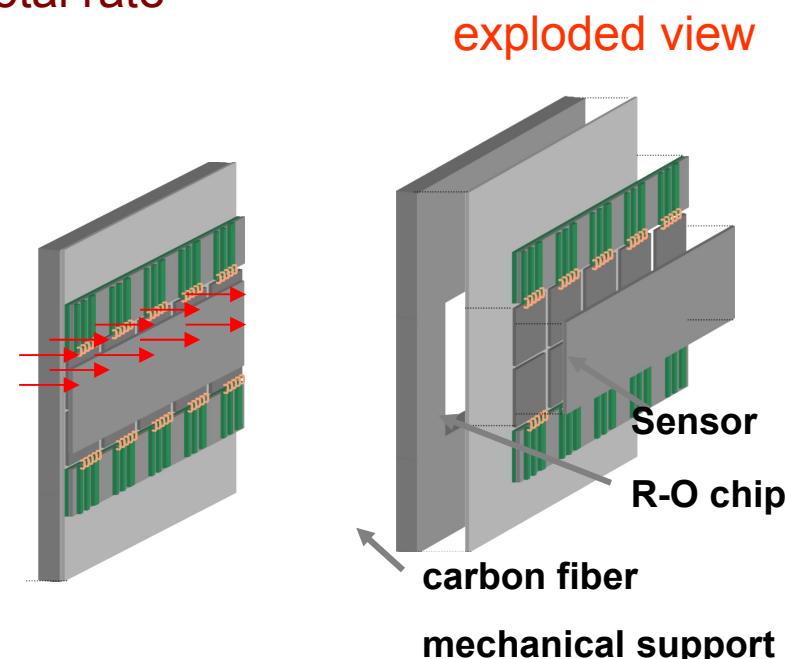
Three tracking stations to provide a precise measurement of K^+ beam
(momentum, direction and time)

main features

- low mass (multiple scattering),
- operating in vacuum
- severe environment: 1.5MHz/mm², 800 MHz total rate

Solution: silicon pixel stations

- 60x27 mm² area (beam profile)
- 300x300 mm² pixel size
- 200 mm thick sensor (15000 e⁻ for a MIP)
- 10 R-O chips 100 mm thick cmos
- 130 MHz rate/chip (max)
- 140 nm technology
- 0.5 X/X_0 /station material budget
- 200 ps /station time resolution
- 14 mrad track resolution
- 0.15 GeV/c momentum resolution



Straw chamber spectrometer (I)

To measure momentum and direction of K^+ decay

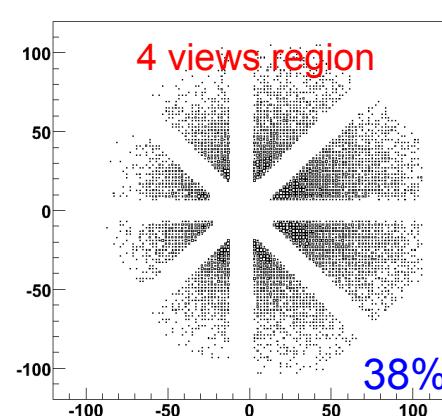
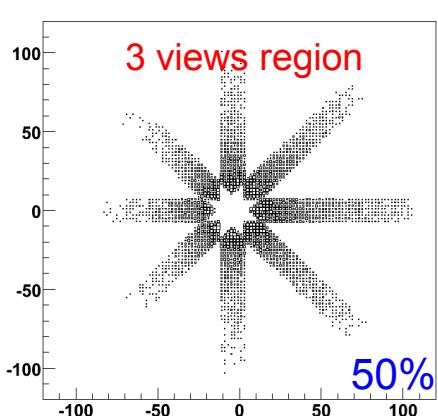
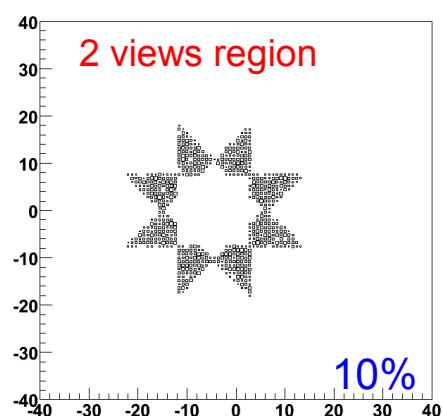
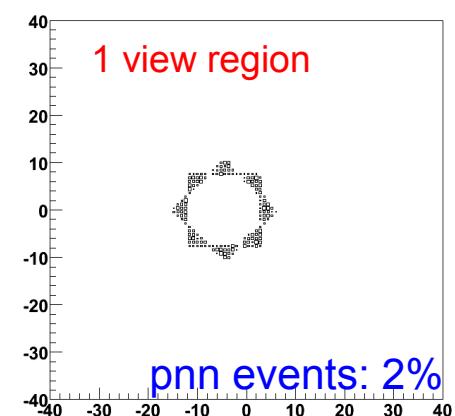
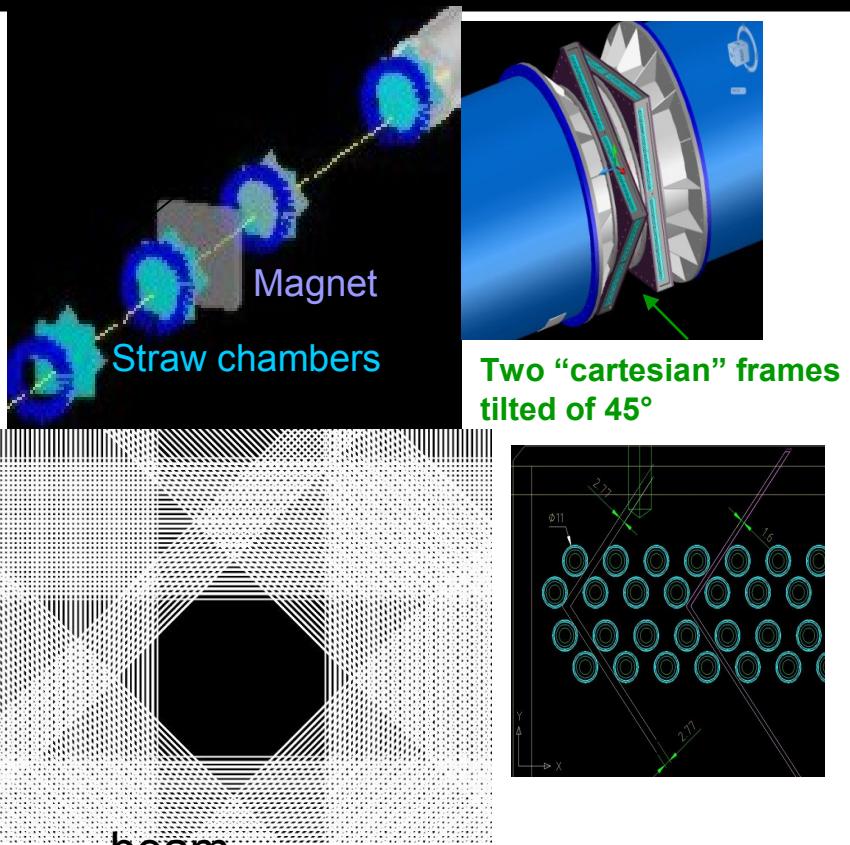
Requirements:

- low mass (multiple scattering),
- operating in vacuum
- good spatial and momentum resolution
- small inactive area around primary beam

Solution:

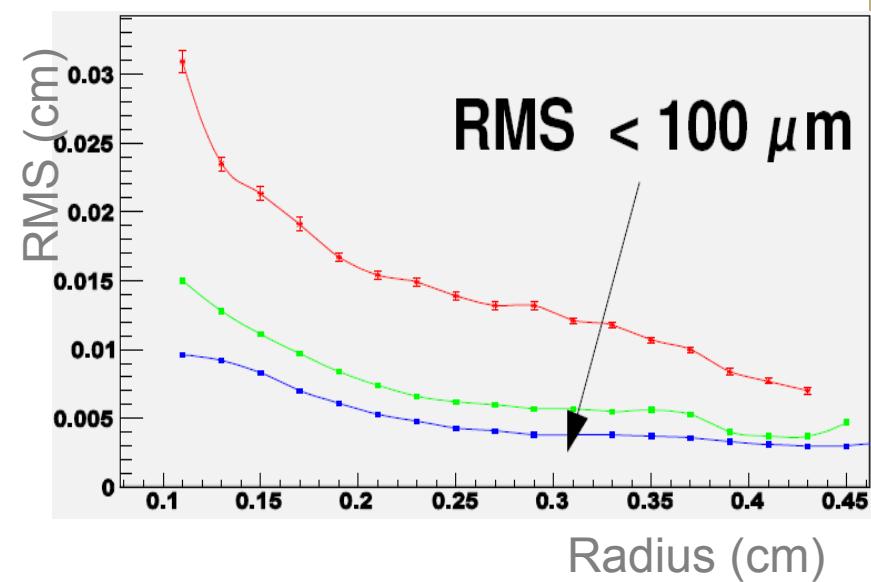
four straw chambers and one magnet 256 MeV/c P_t

- 4 view/chamber XYUV
- 4 staggered layer/view (L/R ambiguity)
- 500 straws/view, 8000 grand total
- 9.6 mm radius mylar tube
- 2.1 m long
- $X/X_0 \leq 0.1\%$ per view



Straw chamber spectrometer (II)

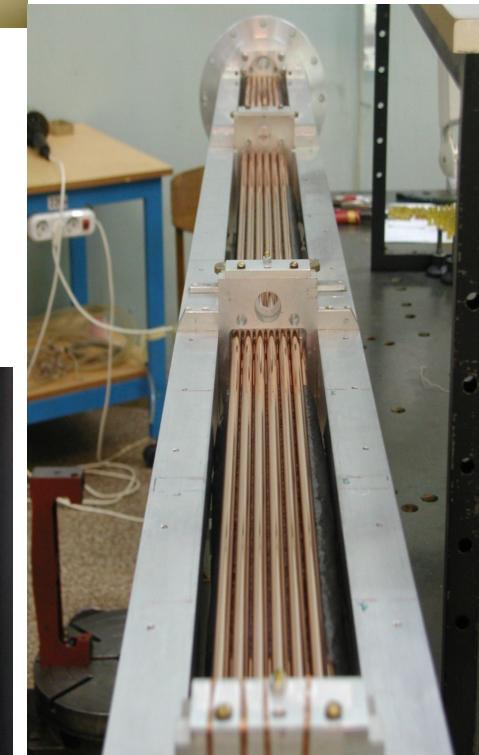
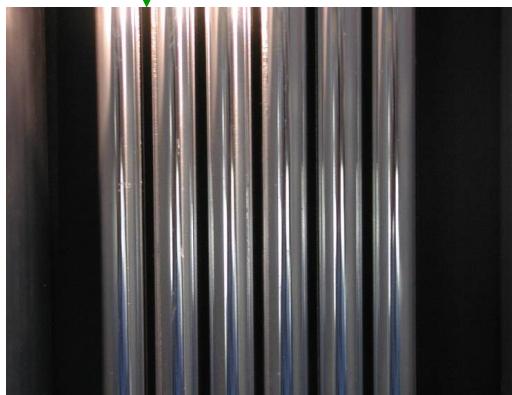
Prototype test beam in vacuum
muon tracks reconstruction



ultrasonic welded mylar
• no glue no out gassing
• better load and resistance



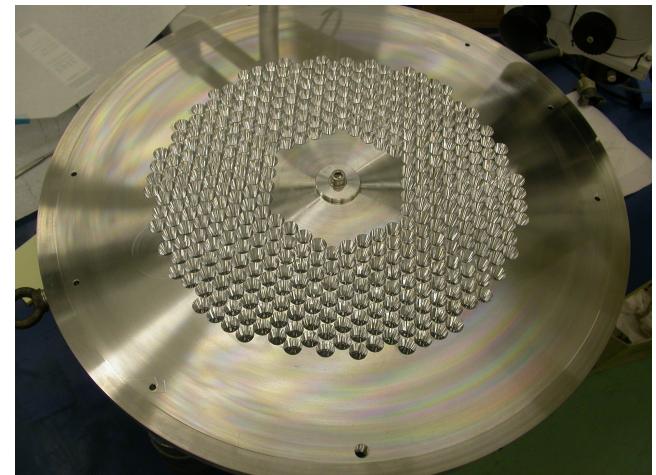
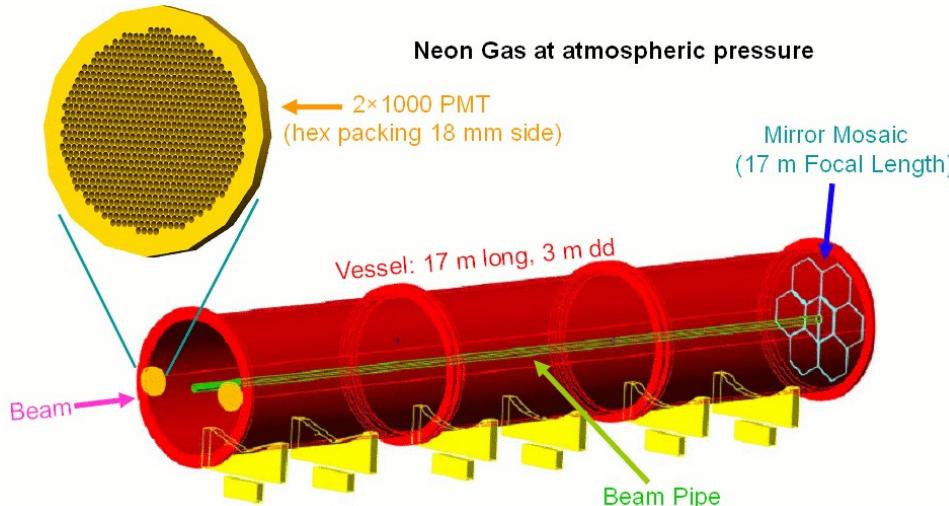
Small gap for diameter expansion under vacuum



NA62-II: Rich

Requests:

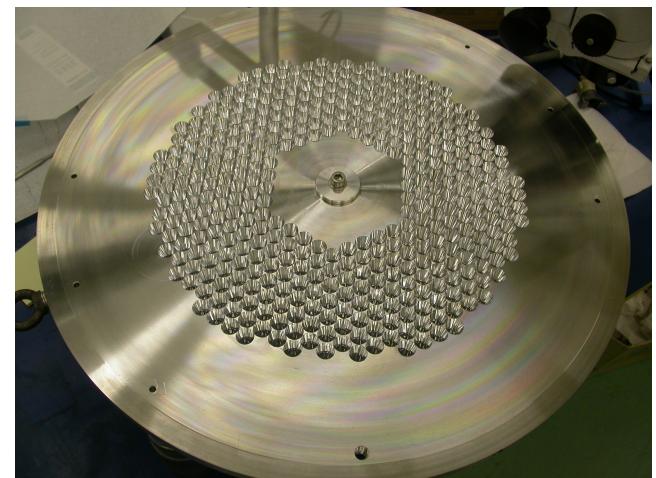
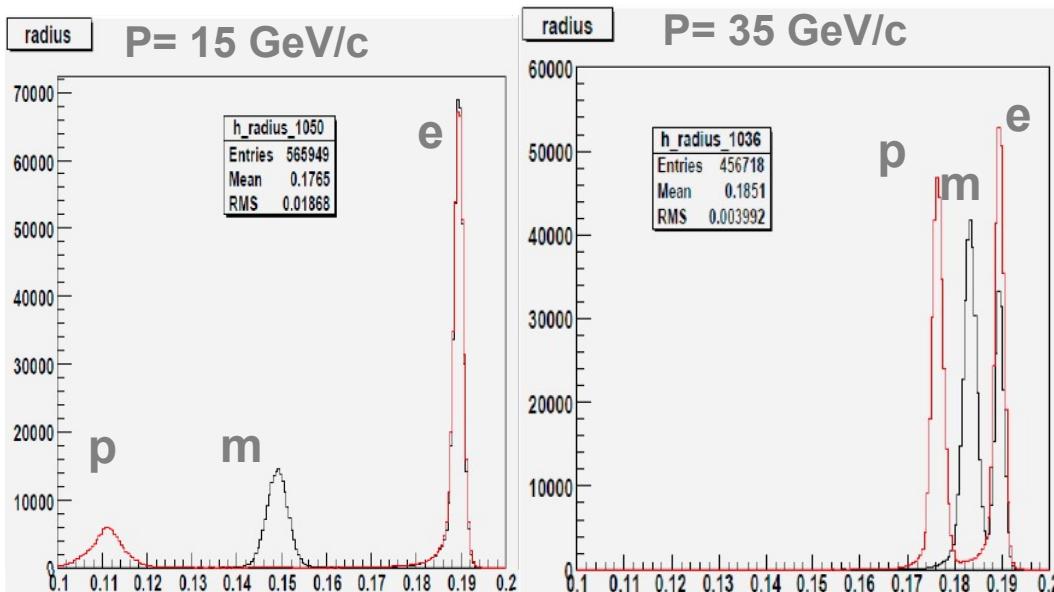
- Provide p/m separation at 5×10^{-3} in the range $15 < p < 35 \text{ GeV}/c$
 - Measure track time with 100 ps res
 - Provide the main trigger for charged particle
 - 18 m long tube filled with Neon
 - Mirrors with f=17 m
 - 2000 single anode PMTs, 1 cm in diameter
 - 18mm “pixel” with Winston cones
- 400PMTs prototype with new readout electronics tested in May



NA62-II: Rich

Requests:

- Provide p/m separation at 5×10^{-3} in the range $15 < p < 35 \text{ GeV}/c$
 - Measure track time with 100 ps res
 - Provide the main trigger for charged particle
 - **18 m long tube filled with Neon**
 - Mirrors with $f=17 \text{ m}$
 - **2000 single anode PMTs**, 1 cm in diameter
 - 18mm “pixel” with **Winston cones**
- **400PMT prototype with new readout electronics tested in May**



Impact of the kinematic reconstruction

The rejection factors estimated by a Geant4 Simulation

Table of resolutions

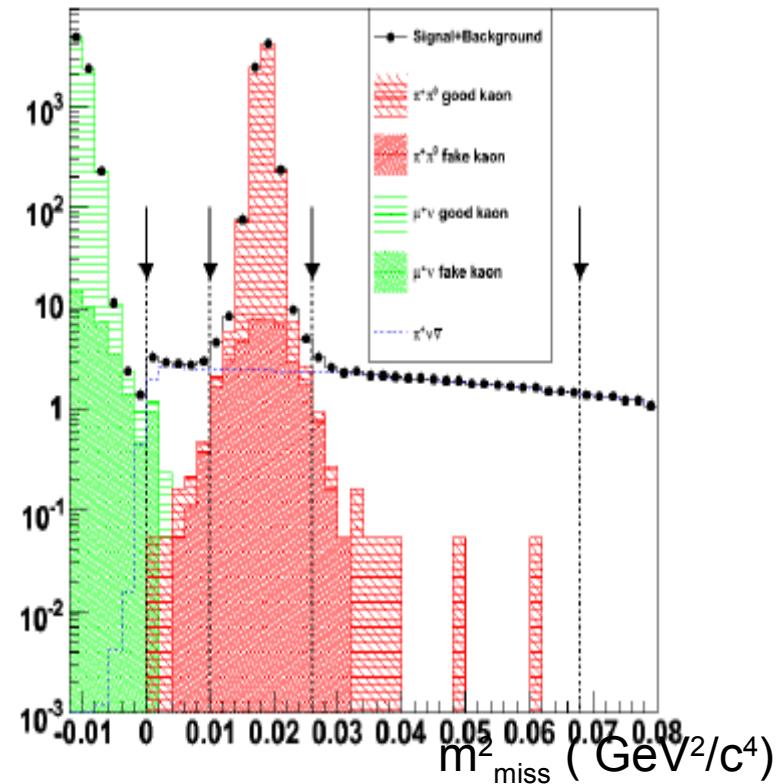
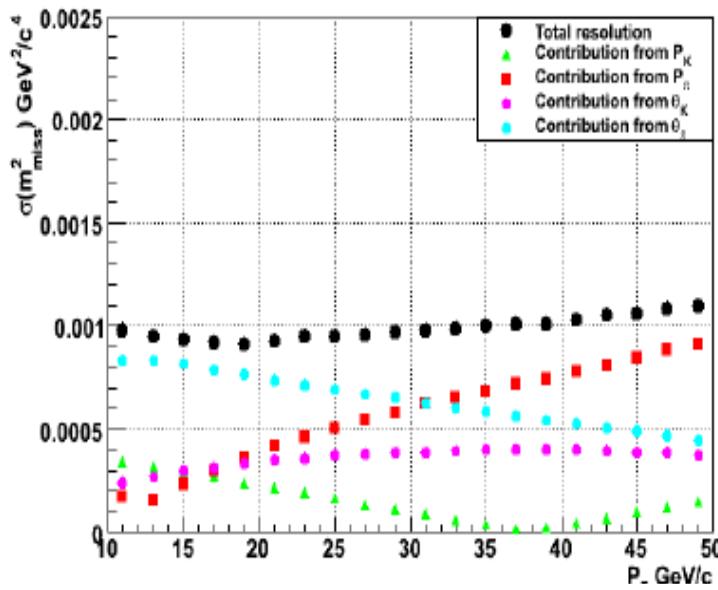
particle	P	direction
K^+	0.2%	17 mrad
p^+/m^+	0.3%	15-45 mrad



Table of rejection factors for two body decays

decay	R.F.
$K^+ \rightarrow p^+ p^0$	10^4
$K^+ \rightarrow m^+ n$	10^5

Main sources of inefficiencies:



The Photon Veto System

To obtain the required rejection factor on $K^+ \rightarrow p^+ p^0$ a photon detectors system with **10^8 rejection factor on $p^0 \rightarrow gg$ is required**

Three different angular regions to be covered

- LAV: Large Angle Veto: (10:50 mrad)
- LKr: Liquid Krypton calorimeter (1:10 mrad)
- IRC and SAC <1mrad

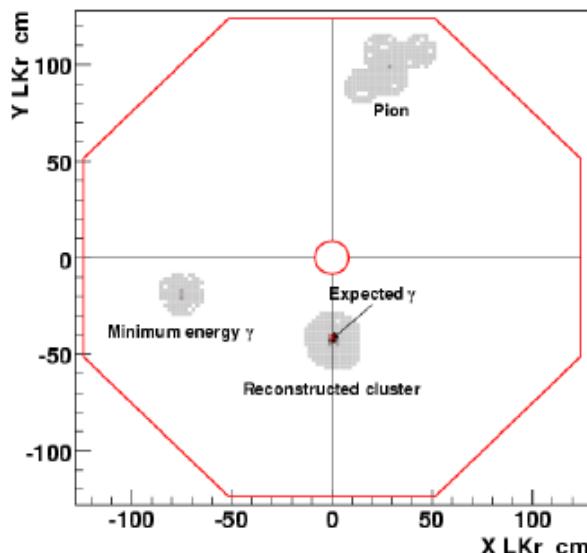
requiring $P(p^+) < 35 \text{ GeV}$ we get $P(p^0) > 40 \text{ GeV}$ and high energy photons: photons $> 1 \text{ GeV}$ hit the LKr \rightarrow high detection efficiency

NA62-II: LKr



Requests:

- Very high efficiency on forward photons
($1 < \text{acceptance} < 10 \text{ mrad}$)
- Good time resolution
- Na48 LKr calorimeter
- The efficiency has been measured with a **special run** in 2006
- $< 10^{-6}$ for $E > 10 \text{ GeV}$, $< 10^{-3}$ for $2.5 < E < 5.5 \text{ GeV}$



- **New cryogenics system** and new FE readout already done
- **New electronics** to allows faster triggering in construction